Appendix E

Temperature Criteria for Evaluating the Risk of Chinook Salmon and Steelhead Impacts

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Among the fish species inhabiting the lower American River, chinook salmon and steelhead have the greatest sensitivity to exposure to elevated water temperatures. Chinook salmon and steelhead are both anadromous species that have evolved and adapted to coldwater conditions. The American River is located near the southern end of the geographic distribution for both chinook salmon and steelhead. Exposure of these species to seasonally elevated water temperatures in the Sacramento River system, which includes the American River, has been identified as a major "stressor" by CALFED Bay-Delta Program (1997a, 1997b), the California State Water Resources Control Board (1991, 1995), U.S. Fish and Wildlife Service (1987, 1992, 1995; Castleberry et al. 1993), California Department of Fish and Game (Rich 1997), and many other investigators working on salmonid populations within California. Water temperature, for example, was a major factor considered in *Environmental Defense Fund et al. v. East Bay Municipal Utilities District* with regard to both chinook salmon and steelhead.

Each life stage of chinook salmon and steelhead has different physiological responses to water temperature conditions. These responses may reflect chronic and sublethal effects, such as changes in developmental rate, growth rate, or condition, or they may be acute effects resulting in the loss of equilibrium and ultimately mortality (Rich 1997, Schreck 1982, Brett 1971, Boles 1988). The thermal tolerance response of each life stage varies in response to a number of factors, including:

- the acclimation temperature,
- the absolute exposure temperature,
- the duration of exposure to elevated temperature, and
- the overall health and condition of the organisms.

Other factors, such as the availability of prey resources and genetic adaptation, also influence the response of individual fish to temperature conditions. It has also been hypothesized that chinook salmon and steelhead may have greater thermal tolerance near the southern end of their geographic distribution as a consequence of adaptation and evolution under conditions characterized by higher seasonal water temperatures when compared to more northern stocks.

Fish may respond to environmental temperature conditions in a variety of ways, including both physiological and behavioral responses (Crawshaw 1977, Davis 1974, Gray et al. 1977, Taylor 1988). Physiological responses include changes in growth rate and metabolism, susceptibility to disease, rate of embryonic development, frequency of deformity, and mortality (Strange et al. 1977, Thomas et al. 1986, Brett 1971, Clarke et al. 1981, Heming et al. 1982a). Exposure to elevated temperatures may also result in increased levels of physiological stress that, among other factors, may contribute to increased susceptibility to predation (Coutant 1973). Fish may also respond to temperature through behavioral mechanisms, including preferential selection of cooler water microhabitats and avoidance of areas having elevated temperature, resulting in a redistribution of fish to potentially suboptimal habitats. Each of these responses to elevated water temperature may contribute to significant adverse impacts on chinook salmon and steelhead.

Many laboratory experiments have been performed to evaluate the response and thermal tolerance of chinook salmon and steelhead. These laboratory studies have included evaluations on the effects of water temperature on egg and larval development, hatching success, growth rate, health and condition, and swimming performance of juvenile chinook salmon and steelhead (Rich 1997; Boles 1988). Various other investigations have also been conducted to determine the increased susceptibility of juvenile salmonids to predation as a result of exposure to elevated water temperatures, behavioral attraction and avoidance, behaviorally and physiologically preferred water temperatures, and other responses. Laboratory studies have also been performed to determine the exposure time-water temperature (dose response) resulting in a loss of equilibrium and acute mortality for various life stages of both species.

In addition to laboratory investigations, field studies have been performed to evaluate the effects of water temperature on the geographic distribution, survival, health, and condition of adult chinook salmon returning to natal streams to spawn, incubating eggs, egg hatching success and juvenile emergence, juvenile growth and survival, habitat selection, and seasonal water temperatures as an environmental cue for juvenile chinook salmon and steelhead emigration. Although the majority of the scientific literature on effects of water temperature on salmon and steelhead originates from studies conducted in the Pacific Northwest (Oregon-Alaska), investigations have also been performed within California, including studies conducted on the American River (Castleberry et al. 1993). Information from these investigations has been compiled and synthesized as part of the foundation for evaluating potential effects of seasonal water temperature conditions on habitat conditions for both salmon and steelhead within the lower American River.

EGG INCUBATION

The development rate, survival, and hatching success of salmon and steelhead eggs has been found to be very sensitive to water temperature. A variety of investigations have evaluated the effects of constant and variable water temperatures on egg development and hatching success (Alderdice and Velsen 1978, Combs 1965, Heming 1982b, Seymour 1956, Garling and Masterson 1985, Combs and Burrows 1957, Peterson et al. 1977). Many of these investigations, conducted under laboratory or hatchery conditions, were performed on northern stocks.

The most representative studies for the American River may be those Healey (1977) conducted to evaluate the impact of high temperature on survival of Sacramento River chinook salmon eggs and fry. Sacramento River-strain chinook salmon eggs and fry were exposed to temperatures ranging from 6.4°C to 17.2°C (43.5°F to 63°F). Mortalities to the fingerling stage were 80% or more when temperatures during incubation of the eggs and development of fry were 15.6°C to 16.1°C (60°F to 61°F) for a prolonged period. Egg and fry mortalities decreased as temperatures decreased below 15.6°C (60°F) and were insignificant when temperatures were between 14.2°C and 6.4°C (57.5°F and 43.5°F). Healey (1977) concluded that abnormally high salmon egg and fry losses can be expected to occur if river temperatures exceed 14.2°C (57.5°F) during egg incubation.

Results of these investigations are consistent with findings from other studies that have shown that increased mortality occurs when eggs are exposed during incubation to temperatures exceeding 13°C to 15°C (56°F to 59°F) Seymour 1956, Garling and Masterson 1985, Combs 1965). According to the work of

Seymour (1956), a water temperature threshold for chinook salmon eggs of 13°C (56°F) has been selected for use in many analyses. Mortality increased rapidly to 100% for eggs exposed to temperatures of approximately 16.7°C (62°F) or greater.

Exposure of adult chinook salmon to elevated water temperatures prior to spawning has also been identified as a factor contributing to reduced reproductive success. Very little information exists, however, on the relationship between temperature exposure of adult chinook salmon and subsequent viability of either eggs or milt. The National Marine Fisheries Service (1997) reported that acceptable temperatures for adult winter-run chinook salmon migration within the Sacramento River occur within the range 13.9°C to 19.4°C (57°F to 67°F). Water temperatures during winter-run chinook salmon holding and egg maturation are typically 15°C to 15.6°C (59°F to 60°F); however, adults holding at temperatures of 12.8°C to 13.3°C (55°F to 56°F) are reported to have substantially better egg viability (Boles 1988, Hinze 1959). Boles (1988) reported that adult chinook salmon exhibited poor survival when held in hatcheries at water temperatures greater than 15.6°C (60°F). Adults held at water temperatures greater than 15.6°C (60°F) also produced less viable eggs when compared with salmon held at lower temperatures (Boles 1988).

Water temperature is also a significant factor influencing the development and hatching success of incubating steelhead eggs. Remarkably little information, however, is available in the scientific literature for use in establishing specific temperature threshold criteria for evaluating the potential effects of exposure of steelhead eggs to elevated temperatures. Beak Consultants (1989) reported that optimum temperatures for adult steelhead migration were thought to be 7.8°C to 11.1°C (46°F to 52°F), with spawning steelhead beginning to experience chronic stress when exposed to temperatures of 11°C to 15°C (52°F to 59°F). The optimum water temperature for steelhead immigration and spawning and egg incubation reported by Rich (1997) ranged from 7.8°C to 11.1°C (46°F to 52°F).

According to foregoing information, the upper limit of acceptable temperatures was set at 13.3°C (56°F) for chinook salmon spawning and incubation and 11.1°C (52°F) for steelhead spawning and incubation.

JUVENILE REARING AND EMIGRATION

The effect of water temperature on juvenile chinook salmon (fry and smolts) has been extensively investigated, including consideration of behavioral responses, chronic effects (stress and reduced growth rate), and acute mortality (e.g., Brett 1952, Gray et al. 1977, Thomas et al. 1986, Castleberry et al. 1993). Based on data from these studies, temperature guidelines can be established that represent generally acceptable conditions for growth, physiological condition, and avoidance of disease. Temperature guidelines can also be established that are considered to contribute to stressful conditions, reduced growth rates, and other sublethal or chronic effects. Water temperature conditions can also be established, which are generally thought to result in high levels of stress, severe chronic effects (i.e., increased susceptibility to disease, substantially reduced growth, and reductions in indices of health and condition) and loss of equilibrium and acute mortality. Information useful in establishing general temperature guidelines for each of these three conditions is briefly summarized below.

A considerably larger number of field and laboratory investigations have been performed to determine the response of juvenile chinook salmon to elevated temperatures, compared with the available data for steelhead. Many of the temperature-related studies have actually been performed on resident rainbow trout stocks (e.g., Hokanson et al. 1977), rather than anadromous steelhead. The results of many of these studies, however, have shown that rainbow trout and steelhead generally have a higher thermal tolerance than juvenile chinook salmon.

Acceptable Temperature Range

Generally acceptable temperature conditions for juvenile chinook salmon and steelhead can be defined based on studies of behavioral temperature preference, growth rate, health and condition, and resistance to disease. It has been hypothesized, for example, that the behaviorally preferred temperature coincides with the general range of optimum temperatures for juvenile growth and disease avoidance. Brett (1952) determined that the preferred temperature of chinook salmon fingerlings ranged from 12.2°C to 13.9°C (54°F to 57°F), while Banks et al. (1971) recommended 15°C (59°F) for optimum growth of fingerling chinook salmon. Tests performed by Brett (1952) utilized spring-run chinook salmon stocks from British Columbia in determining the behaviorally preferred temperature within a laboratory temperature gradient. The investigations by Banks et al. (1971) measured growth of juvenile chinook salmon in Washington stocks (reared at water temperatures of 50°F, 55°F, 60°F, and 65°F). Banks et al. concluded that of the four temperatures investigated, 15.5°C (60°F) appeared to be the closest to optimum for growth of juvenile salmon, although growth of fish at 18.3°C (65°F) was slightly greater in two tests than growth of fish reared at 60°F. No differences were detected in length-weight relationships or physiological indicators (blood chemistry) of temperature-induced stress within the range of temperatures tested (Banks et al. 1971). All juvenile salmon in these tests were fed to satiation.

Physiological studies conducted on juvenile chinook salmon collected from the lower American River (Castleberry et al. 1991, 1993) did not detect significant differences in a variety of physiological parameters for fish collected under field conditions at temperatures within the range of 15.5°C to 18°C (60°F to 65°F).

Brett et al. (1982) evaluated the relationship between water temperature and growth rate of juvenile chinook salmon (Nochako River stock-British Columbia) as a function of daily ration. At a daily ration of 60%, optimum growth occurred at a water temperature of 15°C (59°F), while maximum growth at a daily ration of 100% occurred at a water temperature of 20°C (68°F).

Rich (1997) reviewed the available scientific literature and concluded that optimum temperature ranges for juvenile chinook salmon fry rearing range from 10°C to 12.2°C (50°F to 54°F), juvenile rearing temperatures ranged from 12.8°C to 15.5°C (55°F to 60°F), and smoltification emigration optimum temperatures range from 10°C to 12.8°C (50°F to 55°F).

Studies of juvenile rainbow trout growth (Hokanson et al. 1977) showed maximum growth occurring at temperatures ranging from approximately 15°C to 17.2°C (59°F to 63°F).

Wurtsbaugh and Davis (1977) evaluated the effects of temperature and ration level on growth of juvenile steelhead trout. As with other growth studies, Wurtsbaugh and Davis found that juvenile steelhead growth was dependent on both water temperature and food consumption, with increasing growth occurring at temperatures up to 17°C (63°F). Growth rates declined at elevated temperatures, particularly with reduced ration levels. Results of growth studies are also consistent with preferred temperature conditions behaviorally selected by juvenile rainbow trout (Javaid and Anderson 1967) in which starved juvenile rainbow trout behaviorally selected a temperature of approximately 18°C (64°F), while trout fed selected a temperature of approximately 22°C (72°F).

Investigations of temperature-induced stress and disease resistance are also consistent in suggesting that generally acceptable conditions occur at temperatures below approximately 15.5°C to 18°C (60°F to 65°F).

Holt et al. (1975) observed increasing mortality for steelhead having columnaris infection as temperatures increased from 12.2°C (54°F) to 20.5°C (69°F). Steelhead experienced 100% mortality at the higher temperature.

Wagner (1974) investigated the effects of water temperature and photoperiod on smolting and migration of steelhead. Temperature did not appear to influence the onset of smolting in these studies; however, fish reared under variable temperature cycles (6.9°C to 18.6°C) were found to migrate in larger numbers when compared with steelhead reared under a constant temperature (12.3°C). Seasonal cycling of temperature and photoperiod combined were found to be important factors influencing smolting and migration of steelhead.

Because of the relatively broad range of acceptable temperatures identified in the literature for juvenile chinook salmon and steelhead rearing and emigration, and the absence of definitive studies of the thermal requirements of chinook salmon and steelhead in the Central Valley (and, specifically, the American River), a specific threshold for American River chinook salmon and steelhead could not be accurately defined. For the purposes of impact assessment, water temperature criteria of 16°C (61°F) for chinook salmon and 18.3°C (65°F) for steelhead were used because they generally fall within the upper range of acceptable rearing temperatures reported in the literature. Therefore, these criteria should be considered guidelines for impact assessment and should not be construed as a specific management or target thresholds for lower American River chinook salmon and steelhead.

Temperatures acceptable for juvenile steelhead smolting have been generally found to be less than the acceptable temperatures for summer rearing. Water temperature affects the rate of smolting in juvenile anadromous salmonids and the ability of juveniles to make the transition from parr (pre-smolt phase) to smolt. Studies have shown that the enzymatic process involved in smoltification is depressed at temperatures below 44.4°F and above 52.3°F (Adams et al. 1975, Wagner 1974). Smolting has been reported to cease when water temperatures increased to 57°F to 64°F (Kerstetter and Keeler 1976, Wagner 1974). McEwan and Nelson (1991) recommended that water temperatures not exceed 57°F during the steelhead smoltification period. The acceptable upper temperature limit for juvenile steelhead smolting in the lower American River was established at 57°F.

Stressful Temperature Range

Temperature conditions resulting in stress for juvenile chinook salmon and steelhead have also been investigated. The California State Water Resources Control Board's 1991 Water Quality Control Plan recognized an upper threshold temperature objective for protection of fall-run chinook salmon at a daily average water temperature of 20°C (68°F) during spring (April–June) and fall (September–November) periods of juvenile emigration and adult immigration. National Marine Fisheries Service (1997) identified an upper critical temperature threshold of 18.9°C (66°F) as the temperature above which sublethal impairment would be expected. Growth rates for juvenile chinook salmon have been observed to decline, particularly at reduced ration levels, at water temperatures above 15.5°C to 18.3°C (60°F to 65°F). Banks et al. (1971) did not detect significant differences in body condition or blood chemistry for juvenile chinook salmon reared at temperatures below 18.3°C (65°F). Juvenile salmon and steelhead have been observed to experience increased susceptibility to disease (Johnson and Brice 1953), reduction in the time to death after exposure to pathogens, and increased disease-induced mortality when reared at temperatures above approximately 18.3°C (65°F). Juvenile chinook salmon have also been observed, in laboratory tests, to behaviorally avoid temperatures exceeding approximately 18.3°C (65°F), which is generally consistent with the hypothesis that juvenile chinook salmon and steelhead will avoid stressful or suboptimal temperature conditions when possible.

Acute thermal tolerance (water temperatures resulting in loss of equilibrium and direct mortality) has been investigated for juvenile chinook salmon (Brett 1952, Hanson 1991). The upper lethal temperature for chinook salmon has generally been found within the range from 22.8°C to 26.1°C (73°F to 79°F). The most directly applicable thermal tolerance studies are those conducted by Hanson (1991: unpublished data) using juvenile chinook salmon from the lower Mokelumne River. Tests were designed to determine the time to loss of equilibrium and time to death (acute mortality) for juvenile chinook salmon (mean length 97 millimeters) exposed to constant elevated temperatures from 17.8°C (64°F) to 27.2°C (81°F) for fish acclimated at 12.2°C (54°F). Juvenile chinook salmon tested at 17.8°C (64°F) experienced no loss of equilibrium or mortality over a period of 10,000 minutes (167 hours). The time to 50% mortality (geometric mean resistance time) ranged from 7,799 minutes at 21.1°C (70°F) to 21 minutes at 27.2°C (81°F). An increase in acclimation temperature from 12.2°C (54°F) to 17.8°C (64°F) resulted in an increase in the resistance time to 50% mortality. Juvenile chinook salmon exposed to a gradually increased temperature experienced a rapid increase in mortality as temperatures exceeded 23.9°C (75°F). Brett (1952) determined the upper lethal temperature to be 25°C (77°F) for juvenile chinook salmon acclimated to temperatures above 15.5°C (60°F).

Juvenile chinook salmon survival on the Sacramento River has also been investigated in a series of coded-wire tag mark-recapture studies performed by the U.S. Fish and Wildlife Service. Baker et al. (1995) reanalyzed results of the U.S. Fish and Wildlife Service studies and predicted that temperatures of 20°C, 22.8°C, and 26.1°C (68°F, 73°F, and 79°F) resulted in 10%, 50%, and 90% mortality for juvenile fall-run chinook salmon.

Growth rate studies have also consistently shown reduced growth (Brett et al. 1982, Hokanson et al. 1977) for juvenile chinook salmon, steelhead, and rainbow trout reared at water temperatures exceeding approximately 20°C (68°F).

EA Environmental Services (1990) also evaluated the effects of temperature on juvenile chinook salmon and classified water temperatures exceeding 20°C (68°F) as medium- to high-stress conditions based on food conversion efficiency and growth rates.

Susceptibility of juvenile salmon and steelhead to disease and the magnitude and rate of disease-induced mortality also increase substantially when fish are exposed to water temperatures in excess of 20°C (68°F).

Conclusion

Temperature criteria have been established for use in impact analyses for the proposed project using available scientific information on the effects of water temperature on various life stages of chinook salmon and steelhead. Recommended water temperature criteria for the fisheries impact analysis are summarized in Table 1. Water temperature criteria include consideration of the sensitivity of each of the key life stages to water temperature and the seasonal and geographic distribution of each of the life stages within the lower American River.

Table 1. Recommended Water Temperature Criteria for Chinook Salmon and Steelhead Life Stages in the Lower American River

Species	Critical Months	Location	Temperature Criterion
Chinook spawning/incubation	October–March	Goethe Park	56°F
Chinook rearing/emigration	January–June	Mouth	61°F
Steelhead spawning/incubation	December–May	Goethe Park	52°F
Steelhead rearing	July–September	Fairbairn WTP	65°F
Steelhead smolting/emigration	March–May	Mouth	57°F

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